Vessel-free flooding of deepwater pipelines using the Copipe SPU

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The Deepwater Pipeline Technology Conference

Hilton Riverside Hotel
New Orleans, Louisiana

March 9-11, 1998

Organized by
Clarion Technical Conferences
and
Pipes & Pipelines International

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Introduction

Newly constructed submarine pipelines are built on the surface and are therefore at ambient atmospheric pressure when sealed and laid on the seabed. The pipelines are then usually flooded with seawater to allow pressure testing, cleaning and connection to platforms and subsea facilities.

In this flooding process pipeline pigs are passed through the pipeline by pumping filtered seawater treated with anti-corrosion chemicals at a pre-set velocity. The operation is supported on the surface by stationary vessels providing pumping and chemical injection equipment, and connected to the submarine pipeline by large diameter high pressure hoses. (See Figure 1).

Conventional pigging and flooding of a pipeline is carried out by pumping water into one end of the pipeline to drive a pig train through it. This usually requires a substantial flow of water at relatively high pressure, which in turn requires a large pump spread of high hydraulic horsepower. This technique is costly in terms of capital equipment and vessel time and is also usually subject to weather dependant stationary vessel time.

Occasionally, for purposes of weight introduction or because of accidental pipeline breakage, pipelines have been "free-flooded" by simply allowing the sea to rush in (sometimes through a rough strainer) with potential for debris (sand or silt) entry and uncontrolled flooding. Subsequent cleaning operations can be costly and inconvenient.

The Copipe SPU utilises the natural hydrostatic pressure differential between the pipeline interior (atmospheric pressure) and the surrounding sea.

In doing this the SPU significantly reduces the need for surface vessel support and associated costs.

In August and September of 1997 the SPU successfully flooded, with full filtration and chemical injection, three pipelines in the North sea. Two 10 inch. diameter and one 6inch diameter lines, each about 9 km long, were remotely flooded without a surface vessel in attendance.

Proceedings of the 1998 Deepwater Pipeline Technology Conference, New Orleans, USA.

Overview

The self-contained unit is placed on the seabed, connected to the pipeline by divers or Remote Operated Vehicle (ROV), and left to carry out the flooding without attendant surface vessel. The SPU controls initial flooding when hydrostatic pressure difference is at its maximum and prevents undesirably high flooding rates. As the pipeline is progressively filled, pressure drops to the point where it eventually falls to equal the driving pressure differential required for a pig train.

At this point flooding ceases and mechanical action is required to complete movement of the pig train to the end of the pipeline. The SPU then uses a skid-based subsea pump to complete flooding. A small surface vessel returns to the site when convenient to support this operation and to recover the SPU. The subsea pump is powered by an ROV or the surface vessel using hydraulic power packs or hydrotest pumps.

How it works

The SPU performs the functions of filtration, chemical dosage and flow control. In initial flooding, seawater enters the SPU through a fine-mesh filter and passes through a Venturi tube. A pressure drop is produced in the waist of the Venturi tube, causing the chemicals to be drawn from the reservoir which, being a flexible bag, maintains the chemicals at external hydrostatic pressure. A flow switch in the chemicals line illuminates an LED to give visible indication on the control panel that flow of chemicals has been established.

Chemical flow rate is controlled by a valve which is pre-set to give the correct flow at the maximum expected rate of flow through the main SPU pipework. As the flow in the main pipework reduces, so does the pressure drop in the Venturi tube and hence the rate of flow of chemicals decreases pro-portionally, maintaining an approximately constant additive concentration.

After the Venturi tube, the main flow passes through a control valve system and then through an orifice plate. Since the action of the control valve system is to maintain a constant differential pressure across the orifice plate, the regulated flow is substantially independent of the pressure of the supply.

Eventually the pressure in the pipeline rises until there is inadequate pressure differential to propel the pigs. At this stage, and when convenient to the project, the ROV (or divers) returns to connect the hydraulic lines to the units boost pump or hook-up ROV, and to open its isolation valve. In this configuration the main flow control valve acts as a check valve to prevent reverse circulation in order that the boost pump output is directed only into the pipeline.

On the inlet side of the boost pump sea water is filtered and has chemicals added in exactly the same way as during initial flooding. A control and instrument panel on the unit allows ROV (or divers) to check flow and pressure measurements as appropriate. (See Figure 6).

Using hydrostatic pressure

By positively using hydrostatic pressure, the Subsea Pigging Unit can: Flood atmospherically, air pressurised pipelines. Filter flooding water to 50 micron (nominal) specification. Where required, allow dosing of chemicals and dye within specified concentrations to flooding water. Be connectable, where required, without divers, by ROV. Be a maximum weight of 7 tonnes. Allow diver or ROV to confirm pressure on unit and pipeline prior to disconnection. Allow diver, or ROV, to confirm total flow of water and chemicals though unit prior to disconnection ensuring QA check on dosing, confirmation of pig receipt etc. Where required, maintain consistent pig speed of between 0.5 and 1 m/second. Where required, allow launch of pig train and multiple pigs. Where required, work in water depth of up to and in excess of 1,000 m.

Development and first use

Over recent years developments in deep, diverless areas have led pre-commissioning service companies to develop high pressure connection systems to allow vessels to flood newly constructed pipelines. This has often involved high pressure hoses or even coiled tubing. It still requires an attendant vessel to remain on station during flooding, with associated cost and risk to the deepwater connection. Newly constructed pipelines are laid containing atmospheric pressure whilst the external pressure of the sea exerts a high differential pressure on the connection. (See Figure 1). The connection can be difficult to deploy and maintain and it is not unknown for hoses or coiled tubing to fracture under these conditions. This can allow the pipeline to free flood in a completely uncontrolled manner with no filtration, chemical injection or regulated pig speed. (Subsequent re-flooding and cleaning operations are costly and inconvenient).

Copipe's experience in flooding, testing and pre-commissioning lead it to consider a different approach. Instead of trying to prevent the sea's hydrostatic head from damaging the connection, the pressure could be harnessed and used to flood the line in a controlled manner.

Copipe then set about establishing a range criteria it felt was necessary to maintain, regardless of how a pipeline was flooded:

- Sea water flood atmospherically air pressurised pipelines
- Where required filter flooding water, usually 50 micron (nominal) specification
- Where required allow dosing of chemicals and dye within specified concentrations to flooding water
- Be connectable, where required, without divers
- Where required maintain consistent pig speed of circa. 0.5 m/sec.
- Where required allow launch of a multiple pig train

Copipe then established the criteria they felt important if they were to use a subsea unit:

- Connected to the pipeline but not connected to a surface vessel.
- Be a maximum weight of 7 tonnes so deployment and recovery could be made from a small vessel (ie survey vessel)
- Allow diver or ROV to confirm pressure on unit and pipeline after flooding and prior to disconnection
- Allow diver or ROV to confirm total flow of water and chemicals through unit after flooding and prior to disconnection.
- Where required work in water depth of up to and in excess of 1,000m.
- Limit and control flow to a constant and regulated output (with reference to line size)
- Control injection of chemicals in correct proportion (single or multiple chemicals)
- Boost feed pressure when required to overcome static head and pig driving pressure to complete flooding

As the concept was evolved and a prototype unit developed, it became obvious that a number of project-specific criteria could impact actual design. Those considerations included specifics such as the amount of chemical the unit would hold and types of ROV hotstab connectors. In advance of definitive project requirements the design was developed to satisfy performance criteria and key items of the design were procured and tested without the fabrication and assembly of a complete skid.

The SPU technology was then patented in all major oil and gas world-wide locations.

Farbrication and testing

Fabrication was carried out throughout a four week period. Key items had already been procured and performance tested separately and together where appropriate. A campaign of component external testing was carried out with each piece of the unit externally tested in test chambers (See Figuress 2, 3 and 4).

While an effort was made to address all concerns it was not possible to replicate actual unit use. An atmospherically pressurised pipeline with an external pressure on the unit could not be simulated. Instead a test run for all items was conducted in the company's underwater base test tank via the SPU subsea boost pump. This allowed, as far as possible, the checking and setting of chemical injection equipment and parameters, flow metering instruments, and the boost pump itself.

Project development criteria

Having taken the design and testing to a point where we were positive we could make the unit work in a real situation, we sought a project on which to put the unit (and concept) to the test.

We had successfully completed the World's First Vessel Based Vacuum Drying in 1996 for McDermott Marine Construction Limited and Shell U.K. Exploration and Production on the Teal / Guillemot Project. (Shell U.K. Exploration and Production is operator in the U.K. sector of the North Sea for Shell, Esso and other co-venturers). We were aware that McDermott Marine Construction Limited were again working with Shell U.K. Exploration and Production on the Kingfisher Project. Discussions ensued and we were fortunate enough to work with McDermott Marine Construction Limited on the Kingfisher and the Marathon Oil West Brae / Sedgwick Joint Development Projects, which were to be "combined" in respect of flooding operations.

Pipeline details were:-

WEST BRAE	
4" Service Line	6083 m
6" Gas Lift	8637m
6" Water Injection	6035 m
12" Production	8574 m
2 ½ " Gas lift	2110 m *
6" Production	2112 m
KINGFISHER	
10" Production P1	8695 m
10" Production P2	8711 m

** Flooded only, not pigged*

We jointly established the Methodology and Schedule to allow the SPU to be deployed and connected from the Seateam Survey Vessel, Markab. This vessel was to be in the field in any case, so the potential saving on use (including weather risk and so on) of a DSV was significant. The DSV was also already deployed on the Project.

We had previously felt project specific criteria would alter how we had envisaged a finished unit and this proved to be the case.

Significant differences between our concept and what we actually built after interface with McDermott Marine, Seateam and the ROV subcontractor Sonsub were:-

- positioning of key items affecting centre of gravity to ease deployment
- positioning of chemical storage tank to assist above

- positioning of hot stab and valve handles for ROV access
- optimal skid colour for subsea visibility
- storage of jumper hose
- use of jumper hose swivels to allow ROV manoeuvrability
- lifting arrangements.

A project S.O.R. (Statement of Requirement) was agreed with MMCL. Developed with the client and other vendors, the project requirements resulted in a unit that would allow both the concept and project criteria to be incorporated into the final design. Final fabrication was then carried out by the fabrication division of Copipe's parent company Progenitive Services Ltd. (PSL).

The produced statement of requirements (S.O.R.) was used to manufacture the SPU and project engineering was run in parallel to this process to ensure Project objectives were satisfied.

Ongoing interface engineering between all parties was a priority and regular meetings and briefings ensured a good cross-communication was achieved.

Copipe was allowed input into the following key areas by MMCL to ensure maximum benefit was to be obtained from the use of the SPU:

- Pig Design - to ensure differential pressures to be encountered were minimised without loss of performance
- Pig Trap Design - to ensure minimal pressure drops without loss of efficiency
- Valve Sizing - on pig traps to again ensure maximum benefit was to be obtained from SPU
- Chemical Selection - to minimise number of products whilst still fulfilling specification

The vessel available to MMCL was the Seateam Markab. This vessel was to carry out survey work as well as some construction related activities and would be in the fields regardless of flooding operations. Use of the SPU from the Markab allowed the DSV (Semi 2) expected for flooding to be used on other activities with resultant savings in cost as well as schedule flexibility.

The SPU was mobilised in earnest for actual flooding of the Kingfisher P1 and P2 pipelines on Sunday the 20th of July.

It was convenient to deploy and recover the SPU whilst the vessel was otherwise engaged, prior to flooding operations, to both test the units manoeuvrability as well as familiarise the ROV crew. (See Figure 10).

At 20.40 hours on August 11th, the SPU was connected to P1 pipeline Kingfisher field, and activated by ROV. The world's first operation of this type then commenced. Following ROV operations to allow launch of the two pig train, the vessel confirmed all was in order and left the site. The SPU was left in operational mode.

The actual flooding time before Boost Pump operation was required was approx. 4 - 5 hours. Boosted flow was used to complete flooding operations. Higher than expected pressures were encountered after one line volume had been pumped and on pig inspection, following removal and recovery of the pig receiver, debris in the receiver was found to have been the reason.

The second Kingfisher pipeline, P2, was likewise flooded, without incident, between August the 15th and 16th.

On Saturday the 30th August, at 1842 hours, the SPU was activated having been connected to the 6" West Brae production pipeline. Flooding was again completed without incident.

Lesons learned

- Use of heave compensated cranes will ease deployment and recovery.
- Side panel impact protection will be advantageous.
- ROV (if applicable) manoeuvrability is critical as is ease of hot stab connections.
- SPU can be left unattended on seabed for long periods.
- Operation of boost pump by ROV improves efficiency of subsea and vessel operations.
- SPU works.

Future developments

Apart from practical improvements to the unit we have already started to consider how we can improve the systems performance and benefits.

Because of the lack of depth restrictions we foresee great potential use in deep water areas and developments.

For large, long pipelines, we have a design already in place to actually incorporate the SPU into the initiation or tow heads. This would allow a multi connection of simple subsea chemical tank skids allowing a virtually unrestricted length of pipeline to be flooded with the SPU.

Use of seawater driven hydraulic boost pumps will allow hydrotest pumps to complete the flooding prior to carrying out hydrotesting operations, an additional benefit to customers as well as increasing our own business.

Use of onboard ROV power to operate the Boost Pump will also increase the Units autonomy and decrease the reliance on surface vessel connection, even for short periods.

Complementary services

The ability of the SPU to run pigs at constant speeds ideally supports many logging and inspection operations. Copipe have developed a number of intelligent pigs which can be run by the SPU to provide information on as laid pipeline condition, as well as linking to various analysis packages to facilitate fitness for purpose assessment, and rectification if necessary.

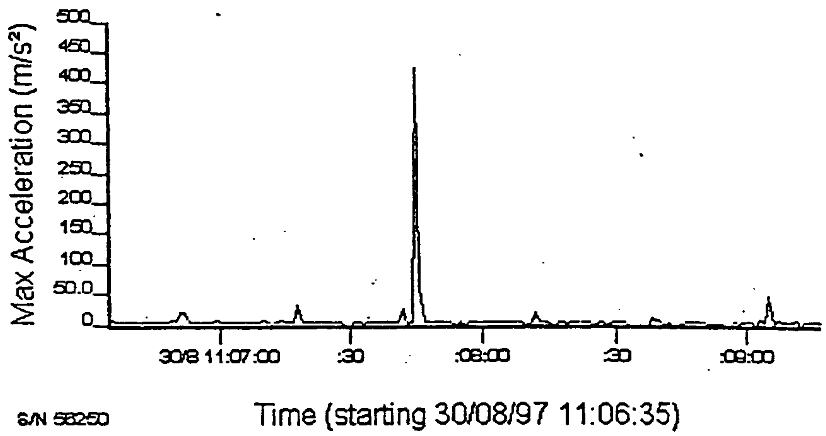
Intelligent gauging pigs

These are extremely simple vehicles, which use an impact logging device to record the location of any gauge plate impacts suffered during a gauging run. This enables false indications (for example at launch or recovery) to be discounted, or any actual impacts to be located on the pipeline with precision. To maintain the simplicity of these tools, they are usually run without an external odometer, and features are located relative to weld locations.

The trace (above, right) shows a gauge plate impact (the large 450 ms^{-2} spike) along with the much smaller impacts due to the tool contacting weld beads. This data was collected in an 8 inch diameter pipeline.

Out-of straightness measurement and control

Copipe have developed an intelligent pig specifically to measure the local curvature of pipelines. The tool uses inertial measurement techniques to precisely measure the amount of curvature (and thus bending strain) along the pipeline's length in both the horizontal and vertical planes. This tool is designed to be fully compatible with the SPU system, and it can be placed in a subsea launcher or initiation head weeks or months prior to the time it is to



be run. The tool activates on launch, and is totally passive up to the time of launch. No external signals are required for activation, and the tool begins logging accurate data within 2 seconds of launching.

On recovery, the tool contains precise centreline trajectory data for the pipeline which can be downloaded into proprietary engineering packages for assessment. Any features which are outwith the design limits for the pipeline may then be corrected by various stabilising methods, or by lowering with an excavation system such as the JetProp. Conversely, sections of the line which are not requiring stabilisation may be left in place as is, thereby optimising the costs of stabilisation.

CAD PRODUCED DRAWING – NO MANUAL REVISIONS ALLOWED– DO NO[...]LE. IF IN DOUBT ASK

Figure 1

Conventional Pigging from Vessel

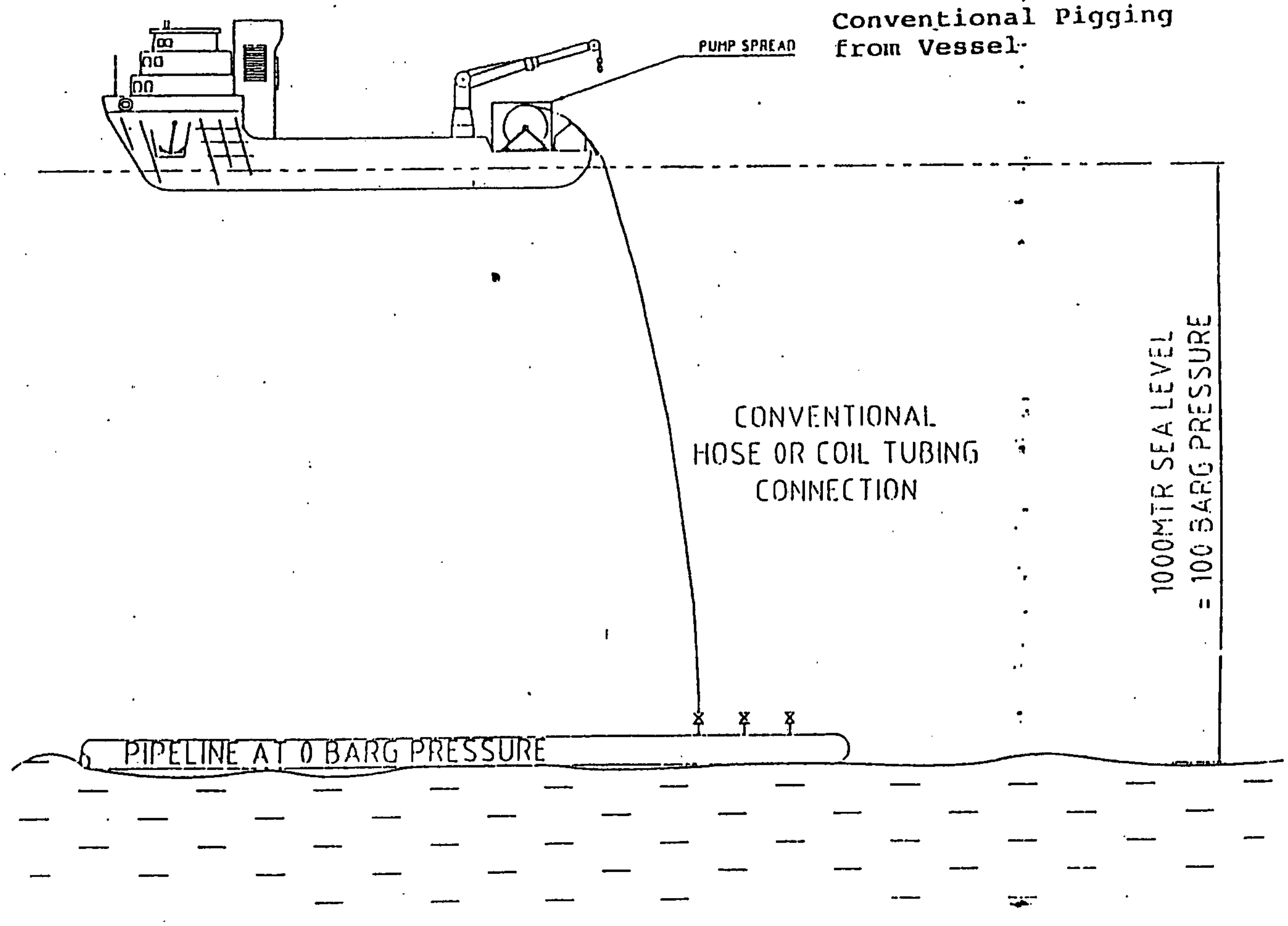


FIGURE 1

TOLERANCES UNLESS OTHERWISE STATED

MACHINING | FABRICATION

ANGULAR ± 0.5° | ANGULAR ± 2.5°

PLATFORM/ SITE

PROJECT

COPIPE

CLIENT: CSL

ENGINEER: C CRABB DATE 13.09.97 C CRABB

DRAWN: J G LYNCH DATE 19.09.97 J G LYNCH

CHECKED: C.CRABB DATE 18.09.97 C CRABB

APPROVED: C.CRABB DATE 13.09.97 C CRABB

SCALES: NTS SIGNATURE

TITLE: CONVENTIONAL P[...] FROM VESSE[...]

DRAWING IDENTIF[...]

PROJ No DRAWING NUMBER

CSL00[...]

REV DATE REVISION DRN CKD

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Figure 2 Individual Component Performance Testing

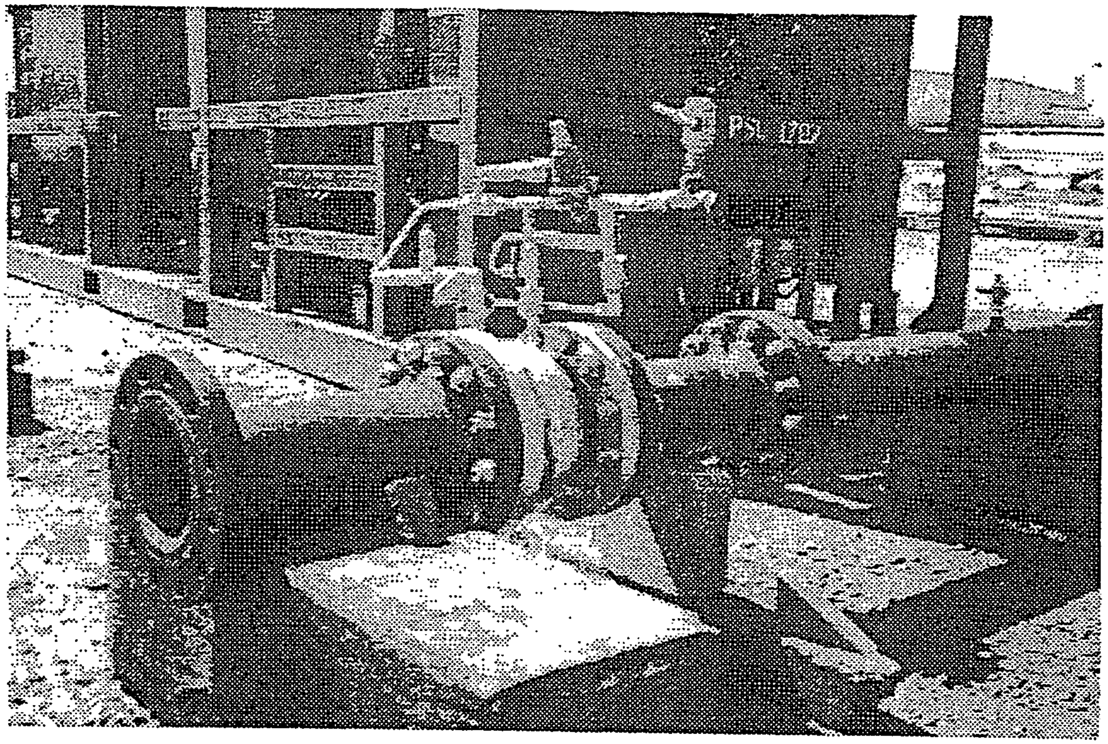

Figure 3 Fabrication of SPU

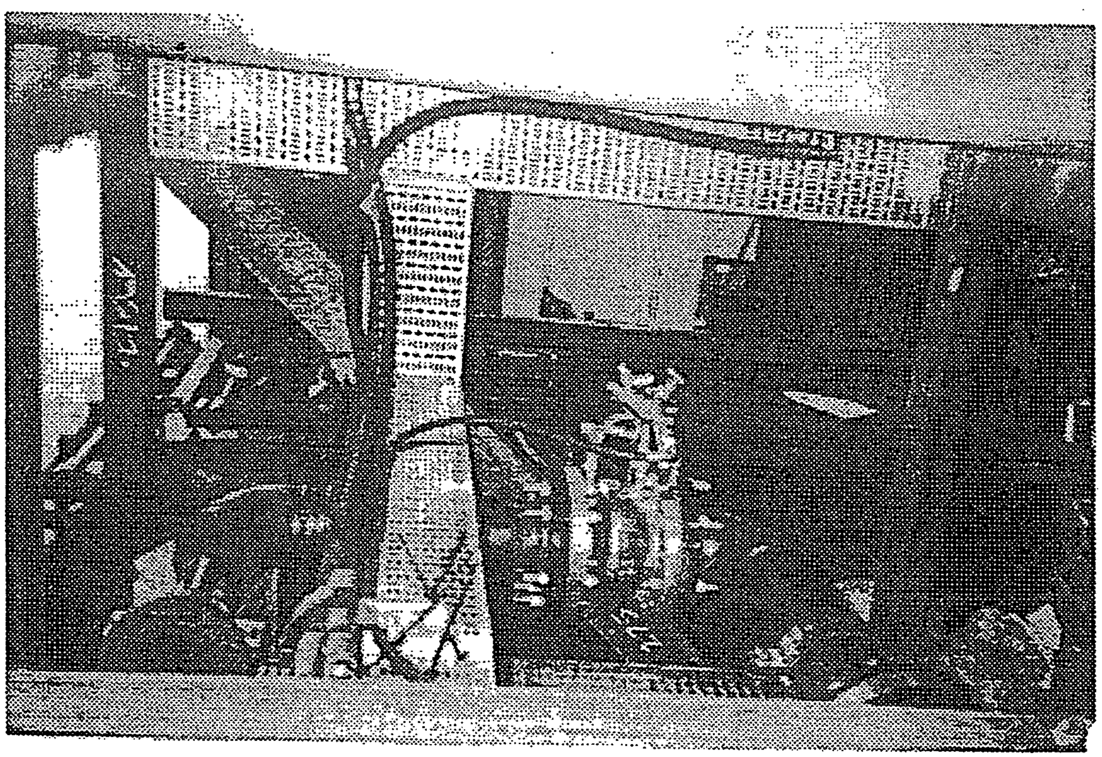

Figure 4 External Testing In Pressure Chambers

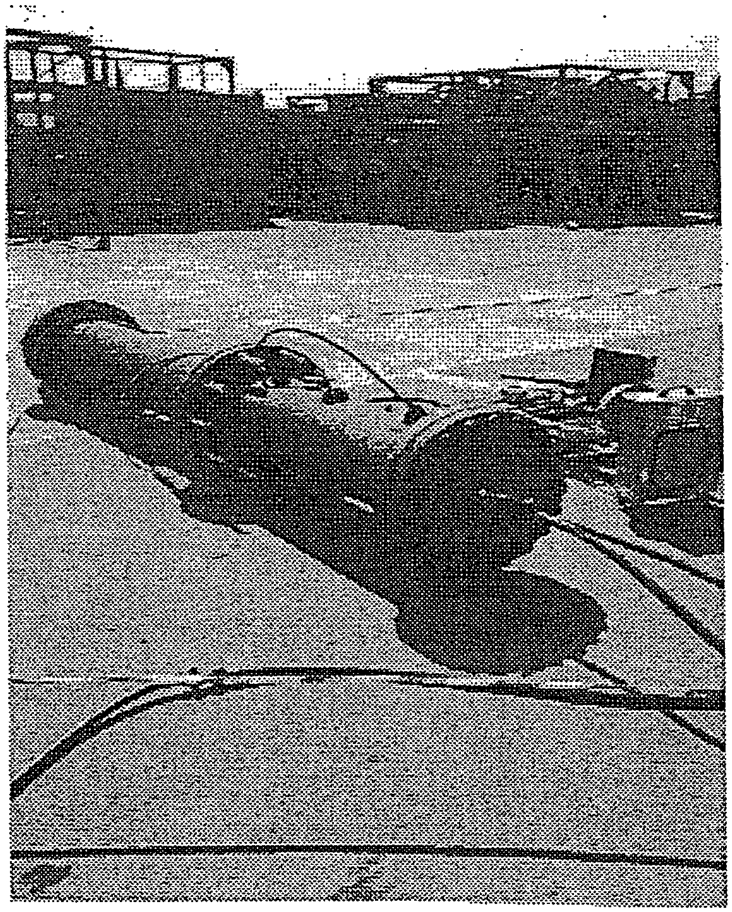

Figure 5 Completed Unit Performance Testing

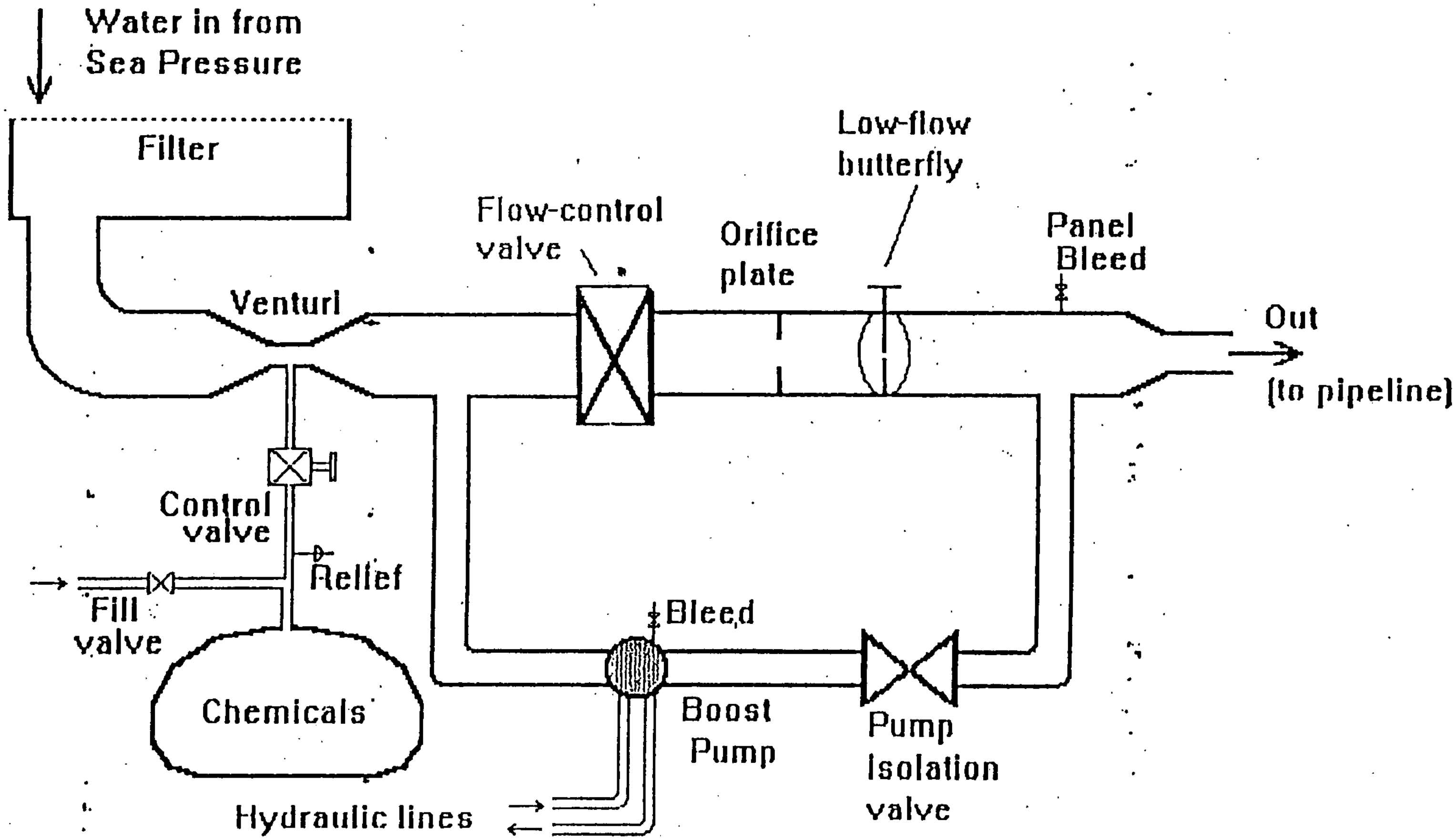

Figure 6 Schematic diagram of flow system in the SPU.

Figure 7 Flexible Chemical Bag

Figure 8 Skid Mounted Subsea Boost Pump

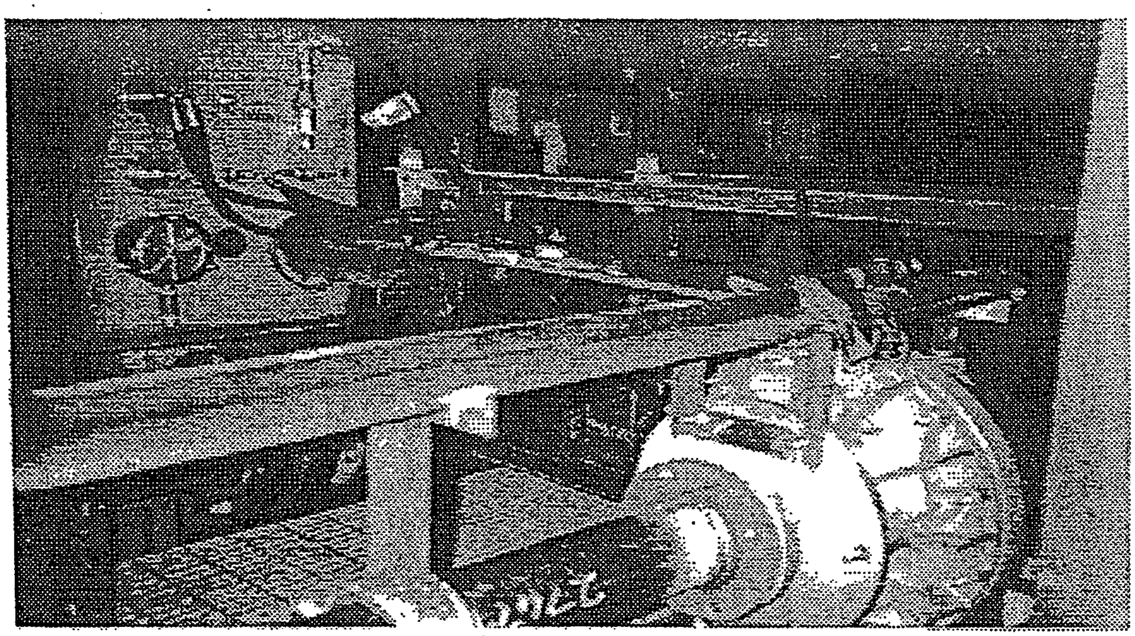

Figure 9 SPU Loading Out On Markab

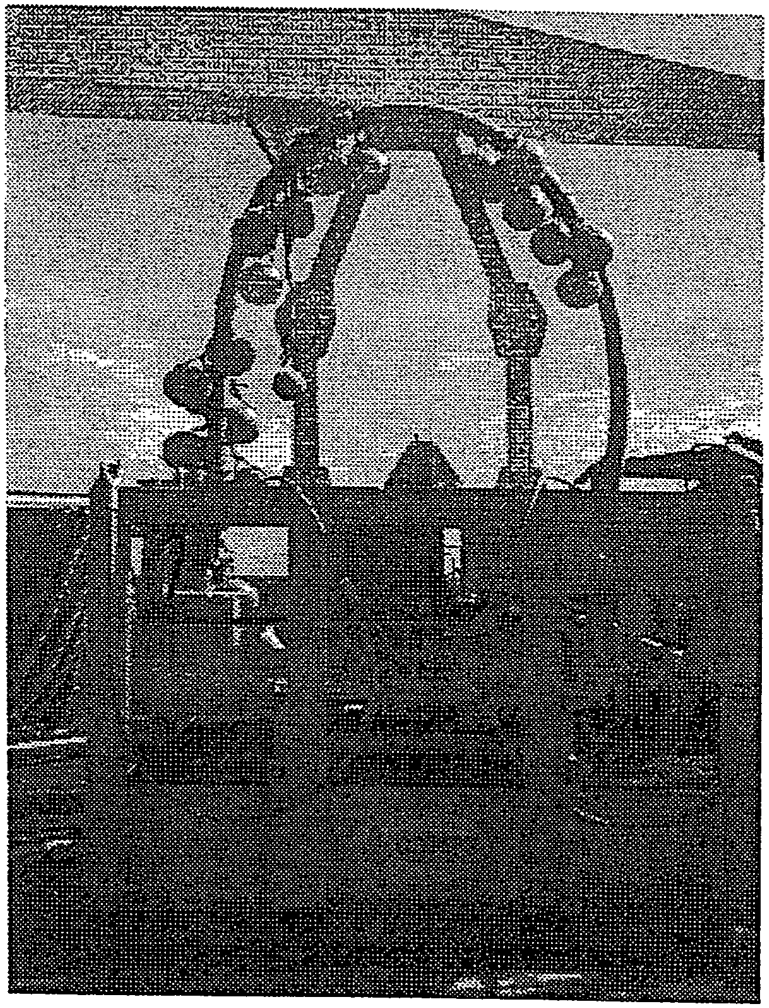

Figure 10 SPU During Subsea Deployment

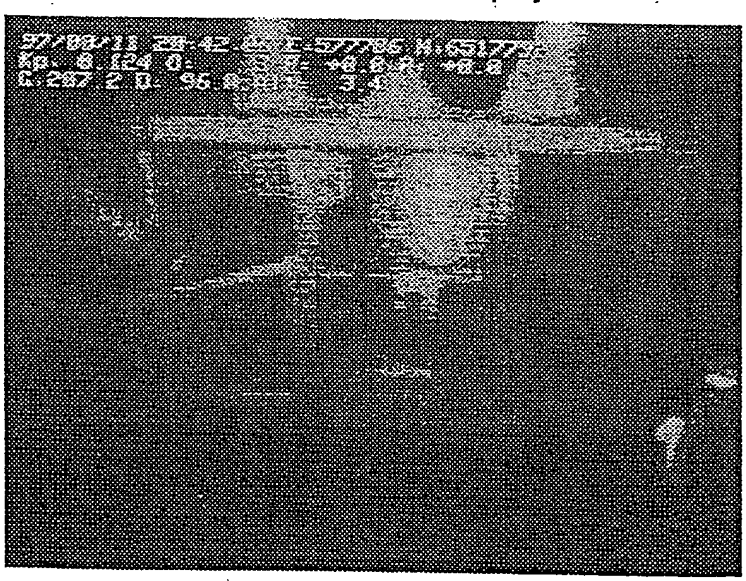

Figure 11 SPU Instrument Panel During Operation

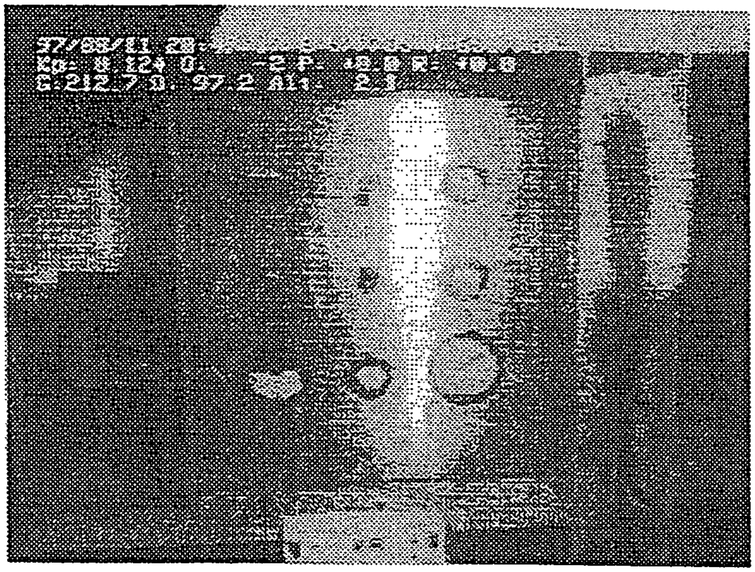

Figure 12 Dye Traces After Hot Stab Disconnection From Pipeline, Post Operation